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Ex Parte

Mr. William F. Caton
Acting Secretary
Federal Communications Commission
1919 M Street, Room 222
Washington, D.C. 20554

RE: CC Docket 92-297

Dear Mr. Caton:

In accordance with the Commission's rules governing ex parte presentations, please be advised that today, Larrie Sutliff, Scott Seidel and the undersigned representing Bellcore met with Donna Bethea, Jennifer Gilsenan, Mike Marcus and Tom Tycz of the International Bureau and Bob James and Susan Magnotti of the Wireless Bureau to discuss the results of the Bellcore study performed on behalf of the International CellularVision Association (ICVA) on co-frequency sharing of the 28 GHz band by the local multipoint distribution service (LMDS) and the fixed satellite service (FSS). Attached is a copy of the study and material used during the ex parte presentation.

Michael J. Knapp

Attachments

Copy w/o Attachments to:
Donna Bethea
Jennifer Gilsenan
Robert James
Susan Magnotti
Mike Marcus
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Interference Analyses for Co-Frequency Sharing of the 28 GHz Band by the Local Multipoint Distribution Service (LMDS) and the Fixed Satellite Service (FSS)

Executive Summary

The Local Multipoint Distribution Service (LMDS) and the Fixed Satellite Service (FSS) can share the 27.5-29.5 GHz frequency band with 99.9% availability for both services. This report describes three major steps that have been taken to achieve 99.9% LMDS availability. First, LMDS system descriptions have been slightly modified to increase their tolerance to interference from co-frequency FSS uplinks. Next, the FSS and LMDS deployment scenarios described to the 1994 28 GHz Negotiated Rulemaking Committee (NRMC) have been used to compute the availability of LMDS systems in the presence of interference from FSS uplinks. Multiple conservative assumptions were made to insure that the availability of deployed LMDS systems will be greater than the availability computed here. The third major step has been the development of an FSS/LMDS Spectrum Protocol that reduces the number of co-frequency interference exposures between FSS uplinks and LMDS receivers. The protocol does not impact the capacity of the FSS system or require improved FSS uplink antenna sidelobes. Acceptable LMDS system performance is achieved with or without use of the spectrum protocol.

Interference analyses have been conducted to determine the LMDS system availability in the presence of interference from co-frequency FSS uplink transmissions. The interference scenario considered was derived directly from system usage descriptions supplied by system proponents to the NRMC. The NRMC calculations studied the specific conditions under which interference could occur, but did not investigate how often this interference would actually occur for the described deployments of both services. Based upon a desire for full access to the spectrum by both LMDS and FSS services, rigorous Monte Carlo simulations were performed to simulate FSS and LMDS deployments with realistic subscriber densities in the same geographic area. Multiple conservative assumptions regarding antenna sidelobe control, number and location of simultaneous FSS uplink transmissions, traffic distribution, propagation loss, and weather conditions were made such that the actual availability will be significantly higher than the calculated availability. LMDS system availability is defined as the percentage of time that there will be *no* harmful interference in *any* shared portion of the frequency band, and is calculated as if all subscribers have access to any portion of the band.

In addition to the availability calculations, an FSS/LMDS Spectrum Protocol has been developed to reduce the number of co-frequency interference exposures between FSS uplink transmitters and LMDS receivers and further increase LMDS system availability without affecting FSS capacity or availability. With the spectrum protocol, an FSS uplink will transmit with a carrier frequency that is either outside of the LMDS band (e.g., 29.5-30 GHz for SPACEWAY) or is in the frequency gaps of downstream LMDS transmissions whenever possible. When all of the frequency gaps are occupied by other FSS transmissions, or the FSS bandwidth is wider than each individual frequency gap, the FSS operating frequency will be chosen from an ordered list of frequencies. Ordered frequency lists are assigned on an LMDS cell-by-cell basis so that the frequencies in one cell are different from the frequencies in other cells. By staggering the order of the frequencies, it becomes possible for *all* FSS uplinks in the same satellite footprint (or FSS cell within a footprint) to operate on frequencies that don't cause harmful interference to surrounding LMDS receivers outside a single specified reduced availability LMDS channel, significantly reducing the interference exposure of LMDS receivers outside that single channel. The results of the simulations indicate that system-wide LMDS availability of 99.9% over space and time can be achieved with minimal impact to existing system designs and NO impact to FSS capacity or availability.

1. Introduction

This report builds on the work of the FSS/LMDS 28 GHz Negotiated Rulemaking Committee (NRMC). The Committee wanted to examine interference mitigation factors, but could not study such factors *in sufficient detail* due to time constraints. This report presents the results of further study of mitigation factors that were identified as showing promise at reducing the interference between FSS and LMDS systems. Three major steps towards achieving a co-frequency FSS/LMDS sharing solution are presented in this report. The first major step is to slightly modify LMDS system designs so that they are more robust to interference from FSS uplinks. The second major step is the development of a methodology for quantifying LMDS system availability due to FSS uplink interference. NRMC calculations determined the required separation distances between FSS uplinks and LMDS receivers, but did not fully take into account the number of simultaneously active FSS uplinks in a specific geographic area. This report introduces the concept of LMDS system availability, and computes the availability under a variety of conservative assumptions regarding antenna sidelobe control, number and location of simultaneous FSS uplink transmissions, traffic distribution, propagation loss, and weather conditions. The third major step is the development of an FSS/LMDS Spectrum Protocol that can be used to significantly increase LMDS system availability. With this spectrum protocol, FSS uplinks operate on frequencies as determined by their geographic location relative to LMDS cells. By accepting reduced availability in a single channel, the LMDS service provider is able to offer service with greater than 99.9% availability in the remaining channels.

1.1 Mitigating Factors

Shared use of a frequency band traditionally involves coordination with existing users when a new terminal is installed. New terminals must demonstrate that they will not cause harmful interference into existing stations. This is based on the concept of first-come, first served, where once service is provided, it cannot be taken away because of interference caused by a new station. Since LMDS systems are anticipated to be deployed before FSS systems, the satellite community is uncomfortable with the concept of first-come, first served. If a plan could be developed to guarantee that the FSS systems could operate in the same geographical areas as LMDS systems without degrading LMDS system availability below acceptable levels, then this concern could likely be alleviated. One of the categories of mitigation factors considered by the NRMC was that of operational mitigation factors. Operational mitigation factors would allow for implementation of a plan to reduce the interference caused by co-frequency transmissions. The Bellcore developed FSS/LMDS Spectrum Protocol presented here provides a plan that allows for full FSS implementation in the same geographic areas as LMDS systems without degrading the LMDS system availability below 99.9%. No per-site prior coordination is required, and only a limited amount of information exchange is required to comply with the spectrum protocol. The impact on existing system designs is minimal.

The remainder of this report deals with other potential FSS system design changes and environmental factors. System design changes of antenna sidelobe control and the use of CDMA are investigated to examine their impact on co-frequency sharing. Environmental factors cannot be controlled by a system designer, but it is useful to determine the potential impact of environmental factors on the ability of FSS and LMDS to share the same frequency band. A geometrical analysis of specular reflections is given to examine the impact of these reflections on the separation distance between FSS and LMDS terminals required to avoid harmful interference, and the effect of specular reflections on computed LMDS availability.

1.2 System Parameters Under Study

1.2.1 LMDS Parameters

The LMDS link budgets are taken directly from the system descriptions submitted by the system proponents to the 1994 28 GHz FSS/LMDS Negotiated Rulemaking Committee (NRMC). The CellularVision analog FM video distribution system and the all digital data Texas Instruments 52 Mbps QPSK system traffic that offers a high degree of flexibility in delivering video, telephony, and data simultaneously are considered in this analysis to provide a broad range of LMDS services and architectures. These are two versions of LMDS system designs. CellularVision, Texas Instruments, and other LMDS proponents offer a multiplicity of LMDS services and architectures that could be deployed. The link budgets for the hub-to-subscriber links of the two systems studied here are given in Table 1-1. Four columns of data are shown to provide the link budgets in the NRMC Final Report [1] and the minor system modifications proposed here to facilitate co-frequency sharing. The modifications are highlighted in boldface in the table. The CellularVision link budget is modified to increase the transmitter power per channel by splitting the 50 channels across two 120 W Traveling Wave Tube Amplifiers (TWTAs). The CellularVision system also implements an improved subscriber antenna mask; the characteristics are given in Appendix A. In addition, the minimum required C/(N+I) under clear sky conditions is reduced to allow for a slight degradation in picture quality in the rare occurrence when interference is present. The TI system is modified such that NO power control is implemented in the system. The hubs transmit continuously at full power. This is possible because this TI system had a positive margin before interference was caused into a space-borne satellite receiver [1].

Table 1-1. LMDS link budget parameters used in this study.

LMDS System		Cellular Vision NRMC	Cellular Vision (mod.)	TI NRMC	TI (mod.)
Modulation	**Units**	**FM Video**	**FM Video**	**QPSK 52 Mbps**	**QPSK 52 Mbps**
per channel calculations					
Clear Sky Transmitted Power	dBW	-5.0	**-1.2**	-12.0	**0.0**
Transmitter Antenna Gain	dBi	12.0	12.0	*12.0	*12.0
Power Control	dB	0.0	0.0	12.0	**0.0**
EIRP (rain)	dBW	7.0	**10.8**	12.0	12.0
EIRP (clear sky)	dBW	7.0	**10.8**	0.0	**12.0**
Bandwidth	MHz	18	18	52	52
Edge of Single Cell Coverage	km	4.83	4.83	5.0	5.0
Free Space Path Loss at edge of coverage	dB	135.5	135.5	135.8	135.8
Allocated Rain Loss	dB	13.0	13.0	15.0	15.0
Receiver Antenna Gain	dBi	31.0	31.0	*34.0	*34.0
Received Power at edge of coverage (rain, full power control)	dBW	-110.5	**-106.7**	-104.8	-104.8
Received Power at edge of coverage (clear sky)	dBW	-97.5	**-93.7**	-101.8	**-89.8**
Receiver Noise Figure	dB	6.0	6.0	8.0	8.0
Noise Floor	dBW	-125.4	-125.4	-118.8	-118.8
C/N at edge of coverage (rain, full power control)	dB	14.9	**18.7**	14.0	14.0
C/N at edge of coverage (clear sky)	dB	27.9	**31.7**	17.0	**29.0**
Required C/(N+I) (rain)	dB	13.0	**8.0-13.0**	13.0	13.0
Required C/(N+I) (clear sky)	dB	26.0	**8.0-13.0**	13.0	13.0

*NOTE — TI antenna gain and EIRP numbers include specified tolerances of 3 dB at the hub and 1 dB at the subscriber for antenna mispointing; the modified CellularVision system uses a subscriber antenna with reduced sidelobes

Table 1-2 shows the *estimated* video SNR and resultant picture quality of the CellularVision LMDS system for various levels of C/(N+I). The effect of the interference on the quality of the LMDS system depends on several factors. For an analog video system, the picture quality degrades gracefully as the C/(N+I) decreases. This table indicates that a C/(N+I) of 13 dB gives a picture quality that is considered 'Fine'. This is comparable to the high end of picture quality for a cable system. As the C/(N+I) is decreased below 13 dB, the picture quality continues to degrade, but remains in the 'Passable to Fine' range. Below 8 dB, the video channel quality drops to 'Passable'. This signal quality is the signal quality of the worst channel, and the quality is only degraded for subscribers located in the area affected by the interferer. Note that these picture quality values are estimates. Further work such as rigorous independent subjective viewing assessment tests may be considered. The results for LMDS system availability are parameterized in terms of C/(N+I) so that should further information regarding the relationship between C/(N+I) and picture quality become available, that information can be directly related to the results presented here. The values in Table 1-2 were estimated for identical center frequencies for the desired and interfering signals. In many cases, there will be some offset between the two signals. The presence of a frequency offset effectively improves the signal quality relative to the quality when the center frequencies are coincident. Appendix B contains plots of the CellularVision signal quality in the presence of digital interference at bandwidths of 26.5 MHz and ~1.5 MHz (T1 rate) provided by mm-Tech. The plots show the C/I where the presence of interference is first noticeable to the viewer and where the picture quality is reduced to 'tolerable' levels for C/N of both 31 dB and 16 dB. The graphs in Appendix B indicate that the picture quality remains high for a C/(N+I) between 8 dB and 13 dB. Availability is computed here for a CellularVision analog FM video system at thresholds of 8 and 13 dB. In between these two values, the availability can be computed via interpolation.

Table 1-2. *Estimated* video signal-to-noise ratio and resultant picture quality in the worst channel for the CellularVision LMDS system as a function of received carrier-to-noise plus interference ratio.

C/(N+I)	Video SNR	Picture Quality
26 dB	55 dB	Excellent
18 dB	47 dB	Fine to Excellent
13 dB	42 dB	Fine
8 dB	37 dB	Passable to Fine

A digital video system, on the other hand, will deliver high quality video signals for a C/(N+I) greater than the system threshold with only a minor degradation in picture quality as the C/(N+I) is decreased. For a C/(N+I) below the threshold (13 dB for the TI system studied here), the video channel becomes unwatchable. The 13 dB criterion is thus appropriate for calculating system availability for the Texas Instruments LMDS system.

The duration of the video degradation depends upon the traffic statistics of the FSS uplinks that are the source of the interference. For example, some users could operate in a T1 rate (1.544 Mbps) 'burst' mode where large amounts of data are sent for short periods of time, and others may transmit smaller amounts of data continuously at a lower data rate (and lower transmitter power). Other users may transmit continuously at the T1 rate. Periodic bursty interference over a long period of time may potentially be more annoying than a one-time complete loss of picture for a relatively short period of time. Quantification of such effects is beyond the scope of this study. Anticipated mean holding time and average Erlang traffic density per user statistics used by the FSS proponents to design their networks should be provided for the different data rate users supported by their systems (16 kbps to 1.544 Mbps in the U.S.) so that analyses of the perceived effect of interference can be determined for the small number of cases when interference degrades LMDS signal quality. For the Teledesic system, each uplink transmits in a TDMA mode with a 2.276 msec frame size every 23.111 msec. NTSC video at 30 frames/second has a frame duration of 33 msec, so the TDMA nature of the Teledesic multiple access does not prevent interference from being received during each frame in an analog LMDS video channel.

1.2.2 FSS System Parameters

The FSS system parameters used in the interference and availability calculations are taken directly from the NRMC final report [1]. Table 1-3 summarizes the parameters for the different FSS systems.

Table 1-3. FSS system parameters used to compute interference and LMDS availability.

FSS System	Units	TST (T1 rate)	TST (16 kbps)	TGT (OC-24)	SPACEWAY (T1)
Transmitter Power	dBW	0.85	-19.0	-0.18	0.8
Antenna Gain	dBi	36.0	36.0	50.0	44.2
Single channel bandwidth	MHz	26.5	0.275 (0.225)	800.0	2.0 (1.08)
Power Control	dB	17.1	17.1	17.1	1.7
ITU Sidelobe Discrimination	dB	-38.2	-38.2	-58.0	-47.0
"Cell Size"/spot beam	km^2	2809	2809	391,000	332,000
Spot beam bandwidth	MHz	400	400	800	120
Max. capacity in spot beam bandwidth	#	15	1440	16	60
Average service area per active subscriber	km^2	187	2	24,500	5,530

2. Analysis of Antenna Improvements

One of the mitigation factors identified by the NRMC was the use of antennas with improved sidelobes [1]. Lower sidelobe levels in the direction of the terminals of the other service would reduce the received power level of interference. This Chapter of the report examines the impact of reduced FSS uplink antenna sidelobes and the LMDS system modifications specified in Table 1-1 on the required separation distances between FSS uplinks and LMDS receivers. First, required separation distances are computed for NRMC system parameters to validate the results computed here. Next, the impact of the LMDS link budget modification in Table 1-1 and a range of FSS antenna sidelobe levels on required separation distances are calculated. The calculations show that the modifications to FSS and LMDS system designs can effectively reduce the required minimum separation distances. Reducing FSS uplink antenna sidelobe levels has a greater impact at reducing the amount of harmful interference than does reducing LMDS antenna sidelobe levels. The minimum separation distances that are required to preclude harmful interference directly impact the resultant LMDS availability calculated in Chapters 3 and 4.

2.1 Verification of Results with NRMC Working Group 1A Calculations

The calculation methodology described in the NRMC Working Group 1 report was coded into a C language computer program to compute the interference from FSS uplinks into LMDS receivers. From the computed interference levels, the required minimum separation distance between terminals to preclude harmful interference can be calculated. To insure that the results calculated here agree with the NRMC calculations, the input parameters specified in Table 2.3.1 of the Working Group 1 Report to the NRMC were input into the computer program, and separation distances were calculated. Appendix A documents the comparison between the NRMC Working Group 1A calculations indicating that the results of the calculations presented here are correct.

2.2 Antenna Sidelobe Levels Studied

Required minimum separation distances and LMDS system availabilities using the technique verified in Appendix A are computed with the FSS uplink sidelobe level as a parameter to determine the sensitivity of the results to the sidelobe level. Maximum sidelobe levels corresponding to the ITU antenna mask of 38.2 dB discrimination for a Teledesic Standard Terminal (TST) and 47.0 dB discrimination for a SPACEWAY terminal were used as baseline values for the two systems. Sidelobe discrimination of 40.0 and 50.0 dB were also used based upon Teledesic comments regarding achievable sidelobe levels [2]. Results were also computed with sidelobe discriminations of 56.0 and 68.0 dB based on antennas available in the Andrew Corporation catalog [3]. While these antennas may or may not meet the business needs of the FSS community, it is useful to examine the effect of improved antenna sidelobes on required minimum separation distances and LMDS system availability. Separations between a Teledesic Gigalink Terminal (TGT) and LMDS receivers were calculated with the ITU antenna mask of 58.0 dB and the 68.0 dB discrimination antenna. FSS antenna pattern discriminations are for an angle of 40°

relative to elevation boresight for the Teledesic antennas and 30° for the SPACEWAY uplink antenna. The LMDS antenna patterns used in computations were the same as those used in the NRMC calculations except where noted.

2.3 Required Separation Distance

The required minimum separation distance is the minimum distance between an FSS uplink and an LMDS receiver beyond which harmful interference does not occur. Harmful interference is defined as occurring when the C/(N+I) of the LMDS receiver is reduced below the level specified by the LMDS system proponent (Table 1-1). Required minimum separation distances between a co-frequency FSS uplink transmitter and LMDS receiver were computed for the FSS antenna sidelobe levels described in the previous section. Separation distances were computed as a function of LMDS antenna azimuth angle at angles of 0°, 5°, 45°, and 180° relative to the LMDS boresight azimuth under clear sky and heavy rain conditions (15 mm/hr) for a T1 rate (1.544 Mbps) Teledesic Standard Terminal (TST), a 16 kbps TST, an OC-24 rate (1.24416 Gbps) Teledesic Gigalink Terminal (TGT), and a T1 rate SPACEWAY terminal. Both a CellularVision analog video distribution system and a Texas Instruments 52 Mbps QPSK digital system were studied to encompass a range of LMDS architectures that can deliver a variety of potential services to the end user.

The minimum required separation distances were computed in exactly the same manner as described in the NRMC Working Group 1 report. This includes the computation of interference based upon peak interference spectral density, rather than total interference power. For interference with a narrower bandwidth than the desired LMDS signal, this results in an upper bound of the interference potential. Hence, calculations with a narrowband interferer are conservative, and may significantly overestimate the required minimum separation distances. Under heavy rain conditions, the CCIR model for rain was used at a rain rate of 15 mm/hr which is the 99.9% rain rate in rain region D_2; this is the same rain model used by Teledesic in [4]. Under heavy rain conditions, it is assumed that the rain exists simultaneously on the FSS uplink path, the desired LMDS signal path, and the interference path between the FSS uplink and the LMDS receiver. Note that the separation distances are computed for an LMDS subscriber at the cell edge. Subscribers closer to the hub will have higher received signal levels and smaller required separation distances from interfering FSS uplinks.

2.3.1 Teledesic Standard Terminal Interferer (T1 rate)

Table 2-1 shows the separation distance (km) required between a T1 rate TST uplink and an LMDS subscriber receiver for different FSS antenna sidelobe performance levels and LMDS azimuth angles relative to LMDS boresight. The first number in a table entry is the required separation under clear sky conditions, and the second number is the required separation during 15 mm/hr heavy rain.

The CellularVision FM video distribution system can satisfactorily operate down to a C/(N+I) of 8 dB under heavy rain conditions, providing greater than 99.9% availability with reduced picture quality caused by rain. With co-frequency sharing between FSS and

Table 2-1. Required separation distance (in km) between a T1 rate Teledesic Standard Terminal and an LMDS receiver with the subscriber at the edge of the cell under clear sky/heavy rain conditions for different levels of FSS uplink antenna sidelobes (NRMC system parameters).

[1] The main beam of an LMDS subscriber antenna is small. Hence, an FSS uplink will infrequently be in the main beam of the LMDS subscriber antenna.

LMDS Receiver	LMDS Antenna Direction	ITU Pattern (-38.2 dB)	Small TST (-40.0 dB)	Typical TST (-50.0 dB)	Andrew Parabolic (-56.0 dB)	Andrew SHX Parabolic (-68.0 dB)
Cellular-Vision Subscriber	Main[1]	37.9/12.9	31.0/12.1	9.8/8.2	4.9/6.3	1.2/3.5
	5° Side	4.8/6.3	3.9/5.8	1.2/3.5	0.6/2.4	0.15/1.02
	45° Side	2.4/4.7	2.0/4.3	0.6/2.4	0.3/1.6	0.08/0.60
	Back	0.1/0.8	0.1/0.7	0.03/0.27	0.02/0.14	0.004/0.038
Cellular-Vision Hub	N/A	0.8/4.7	0.7/4.3	0.2/2.5	0.1/1.6	0.03/0.60
TI 52 Mbps QPSK Subscriber	Main[1]	24.2/12.4	19.8/11.7	6.3/7.9	3.1/6.1	0.8/3.3
	5° Side	1.8/4.9	1.5/4.5	0.5/2.5	0.2/1.7	0.06/0.64
	45° Side/ Back	0.8/3.3	0.6/2.9	0.2/1.5	0.1/0.9	0.02/0.30
TI 52 Mbps QPSK Hub	N/A	1.9/5.0	1.6/4.6	0.5/2.6	0.2/1.8	0.06/0.66

LMDS, reduced picture quality will also be caused by interference. Interference, like rain, does not always exist for a particular LMDS subscriber. Under conditions when interference does exist, it is reasonable for the LMDS system to *temporarily* operate at reduced signal quality under clear sky conditions, instead of the clear sky C/(N+I) requirement of 26 dB specified in the NRMC final report which corresponds to studio picture quality. Table 2-2 shows the required separation distances for CellularVision subscriber receivers and a T1 rate TST under clear sky conditions with C/(N+I) thresholds of 26, 18, 13, and 8 dB, respectively with the revised CellularVision link budget. Notice the significant decrease in required minimum separation distance when a lower C/(N+I), and video picture quality, is accepted under clear sky conditions during the rare occurrence of interference.

Table 2-2. Required minimum separation distance (in km) between a T1 rate TST and a CellularVision subscriber receiver at the edge of the cell under clear sky conditions and a C/(N+I) requirement of 26, 18, 13, and 8 dB with the modified CellularVision link budget given in Table 1-1.

[1]The main beam of an LMDS subscriber antenna is small. Hence, an FSS uplink will infrequently be in the main beam of the LMDS subscriber antenna.

LMDS Receiver	LMDS Antenna Direction	ITU Pattern (-38.2 dB)	Small TST (-40.0 dB)	Typical TST (-50.0 dB)	Andrew Parabolic (-56.0 dB)	Andrew SHX Parabolic (-68.0 dB)
Cellular-Vision Subscriber	Main[1]	22.7	18.5	5.9	2.9	0.74
		7.9	6.5	2.0	1.0	0.26
		4.4	3.6	1.1	0.6	0.14
		2.5	2.0	0.6	0.3	0.08
	5° Side	5.7	4.7	1.5	0.74	0.19
		2.0	1.6	0.5	0.26	0.06
		1.1	0.9	0.3	0.14	0.04
		0.6	0.5	0.16	0.08	0.02
	45° Side	0.32	0.26	0.08	0.040	0.010
		0.11	0.09	0.03	0.013	0.004
		0.06	0.05	0.02	0.008	0.002
		0.03	0.03	0.01	0.004	0.002
	Back	0.23	0.19	0.06	0.03	0.008
		0.08	0.06	0.02	0.01	0.002
		0.04	0.04	0.01	0.006	0.002
		0.02	0.02	0.006	0.004	0.002

For the Texas Instruments LMDS system, the separation distances computed in Table 2-1 included the description of power control for hub transmitters where the hub operates at 12 dB below the maximum power level under clear sky conditions. However, the NRMC Working Group 1 calculations for interference from LMDS hubs into FSS satellites showed a positive margin before the TI system would cause harmful interference into a Teledesic satellite [1]. Hence, the TI system may operate at full power at all times in order to provide additional margin against interference from FSS uplinks. Table 2-3 shows the significant improvement in the minimum required separation distance between a T1 rate TST and a TI LMDS subscriber at the cell edge when power control is NOT implemented. There is no performance penalty for not implementing power control; in fact, the increased tolerance to interference improves the delivered service quality.

Table 2-3. Required minimum separation distance (in km) between a T1 rate TST and a TI 52 Mbps QPSK LMDS subscriber at the cell edge with and without hub power control under clear sky conditions.

[1] The main beam of an LMDS subscriber antenna is small. Hence, an FSS uplink will infrequently be in the main beam of the LMDS subscriber antenna.

LMDS Receiver	LMDS Antenna Direction	ITU Pattern (-38.2 dB)	Small TST (-40.0 dB)	Typical TST (-50.0 dB)	Andrew Parabolic (-56.0 dB)	Andrew SHX Parabolic (-68.0 dB)
TI 52 Mbps QPSK Subscriber	Main[1]	24.2 4.8	19.8 4.0	6.3 1.2	3.1 0.6	0.8 0.2
	5° Side	1.8 0.4	1.5 0.3	0.5 0.1	0.24 0.05	0.06 0.01
	45° Side/ Back	0.8 0.2	0.6 0.1	0.20 0.04	0.10 0.02	0.025 0.006

The third column in Table 2-1 (ITU Pattern) is where the NRMC concluded its analysis of co-frequency sharing. With separation distances as large as 37.9 km in the main beam and 2.4 km in the sidelobes, it is not surprising that the Committee could not identify a co-frequency sharing solution. However, by slightly modifying LMDS system designs under clear sky conditions, minimum required separation distances can be significantly reduced. For the CellularVision hub-to-subscriber link, the separation distances for a subscriber at the cell edge are significantly reduced when the required C/(N+I) for acceptable system performance is decreased from 26 dB to 8 dB (Table 2-2). This corresponds to an occasional reduction in picture quality from studio quality to a passable picture. The amount of picture quality reduction depends on the relative locations of the LMDS subscriber and an interfering FSS uplink. The size of the area where an LMDS subscriber receiver is susceptible to interference from an FSS uplink is estimated to be reduced by a factor of over 200. The resultant picture quality is comparable to that delivered by current cable systems. For the Texas Instruments system, cell edge separation distances are reduced by a factor of roughly 4.5 under clear sky conditions when power control is not implemented, resulting in a 20 times decrease in the size of potential interference zones (Table 2-3). This system modification does not adversely affect delivered signal quality. These LMDS system modifications are the first step towards achieving a co-frequency sharing solution. Similarly, the size of the area where an FSS uplink can cause interference is *significantly* reduced when FSS uplink antennas are also improved.

2.3.2 Other FSS Uplink Terminals and Transmission Rates

The required separation distances between LMDS receivers and 16 kbps Teledesic Standard Terminals (TSTs), Teledesic Gigalink Terminals (TGTs), and SPACEWAY uplinks are summarized in Appendix A.

2.4 Impact of Increased FSS Antenna Gain

FSS uplinks may utilize several different types of antennas throughout a deployed system. Use of different antennas impacts the required minimum separation distances between FSS uplinks and LMDS receivers. Implementing a higher gain uplink antenna will allow for either increased tolerance at the satellite for interference from other sources, or decreased interference generation in the direction of LMDS receivers. Table 2-4 shows a portion of an FSS link budget and the impact on interference generated in the direction of an LMDS receiver. Let X be the current satellite uplink transmitter power and D_{t1} be the antenna pattern sidelobe level discrimination relative to boresight in the direction of an LMDS receiver. For the baseline link budget shown in the first two columns of Table 2-4, the transmitted power level in the direction of the satellite is *EIRP*, and the transmitted power level in the direction of the LMDS receiver is $EIRP\text{-}D_{t1}$. Let Y be the increase in antenna gain due to the use of a different uplink antenna. This antenna has a sidelobe level of D_{t2} in the direction of an LMDS receiver. If the satellite uplink transmitter power remains the same, the transmitted power in the direction of the satellite increases by the amount of antenna gain, leading to an increased carrier level at the satellite, and an increased tolerance to the aggregate interference power from terrestrial LMDS transmitters. In the last two columns in Table 2-4, the satellite uplink decreases its power in proportion to the increase in antenna gain Y. This results in the same transmitted power in the direction of the satellite, maintaining the same FSS signal quality as the baseline link budget, while the interference power in the direction of an LMDS receiver becomes $EIRP\text{-}D_{t2}$. The antenna discrimination relative to boresight in the direction of an LMDS receiver is greater for the higher gain (bigger) antenna ($D_{t2}>D_{t1}$), reducing the amount of interference in the direction of an LMDS receiver.

Table 2-4. Impact of a bigger FSS uplink antenna on co-frequency sharing of the 28 GHz frequency band.

	Baseline Link Budget		**Constant P_t for Increased Interference Tolerance**		**Reduced P_t for Decreased Interference Generation**	
Receiver	**Satellite**	**LMDS**	**Satellite**	**LMDS**	**Satellite**	**LMDS**
P_t	X	X	X	X	X-Y	X-Y
G_t	EIRP-X	EIRP-X	EIRP-X+Y	EIRP-X+Y	EIRP-X+Y	EIRP-X+Y
D_t	0	$-D_{t1}$	0	$-D_{t2}$	0	$-D_{t2}$
Subtotal	EIRP	EIRP-D_{t1}	EIRP+Y	EIRP+(Y-D_{t2})	EIRP	EIRP-D_{t2}

For example, consider a Teledesic Standard Terminal with a heavy rain output power of 17.95 dBW (62.4 W) at an elevation angle of 40° and a main beam antenna gain of 36 dBi with the ITU antenna mask antenna discrimination of 38.2 dB in the direction of an LMDS receiver. The antenna gain in the direction of the LMDS receiver is -2.2 dBi, a readily achievable value. The EIRP in the direction of the satellite is 53.95 dBW, and the EIRP in the direction of the LMDS receiver is 15.75 dBW. If the TST uplink antenna is replaced with a 40 dBi gain model, the ITU antenna mask gives 44.1 dB discrimination at 40°. The transmitter power can be reduced to 13.95 dBW for the same EIRP in the direction of the satellite. With this 40 dBi antenna, the gain in the direction of the LMDS receiver is -4.1 dBi. The resultant EIRP in the direction of the LMDS receiver is 9.85 dBW, a 5.9 dB improvement for just a 4 dB increase in uplink antenna gain. Hence, small improvements in FSS uplink antennas lead to reductions in the separation distances required to avoid interference, and consequently, improvements in LMDS availability. This type of improvement is one that is apparently considered common in the Teledesic system design. In [5], Teledesic states that "all data rates, up to the full 2.048 Mbps can be supported with an average transmit power of 0.3 W by suitable choice of antenna size." While improved sidelobe performance with increased antenna size may not be as easy or economical to achieve with phased array antennas as with the parabolic antennas in the Andrew catalog [3], use of the ITU antenna mask *dictates* that the sidelobe performance improves as the antenna size is increased. This occurs because the ITU antenna mask is a function of the ratio of the antenna diameter (size) to the wavelength of the RF frequency (fixed for a given spectrum allocation). Therefore, use of different antennas in eventual Teledesic deployments will lead to required separation distances shorter than those presented here, and LMDS availability greater than the values computed in Chapters 3 and 4.

2.5 Chapter Summary

As indicated by the calculations, minimum required separation distances can sometimes be quite large depending upon the relative positions of the LMDS hub, LMDS subscriber, and FSS uplink. From the required separation distance as a function of azimuth angle around the LMDS receiver, a potential interference zone can be determined. The potential interference zone is the area around an LMDS receiver where a single active FSS uplink will cause harmful interference in at least one LMDS channel. A conceptual view of a potential interference zone around an LMDS receiver located at the cell edge is shown in Figure 2-1. Several different mitigation techniques can be used to reduce the computed size of potential interference zones.

- Reduce minimum required C/(N+I) for LMDS under clear sky conditions from 26 dB to as low as 8 dB for the CellularVision subscriber receivers, implement the link budget modifications in Table 1-1, and an improved LMDS subscriber antenna mask. The potential interference zone is over 200 times smaller for a subscriber located at the cell edge under clear sky conditions
- Operate the Texas Instruments system continuously at full power; don't use power control. The potential interference zone is 20 times smaller for a subscriber located at the cell edge under clear sky conditions
- Reduce sidelobe levels of FSS uplink antennas; each 10 dB improvement reduces the size of potential interference zones by successive factors of 10. This improvement is much greater than the improvement for a comparable decrease in LMDS subscriber antenna sidelobes
- Increase the size of FSS uplink antennas and reduce uplink transmitter power in proportion to the increase in antenna gain to maintain constant EIRP
- More accurately determine the impact of narrowband interference on wideband signals

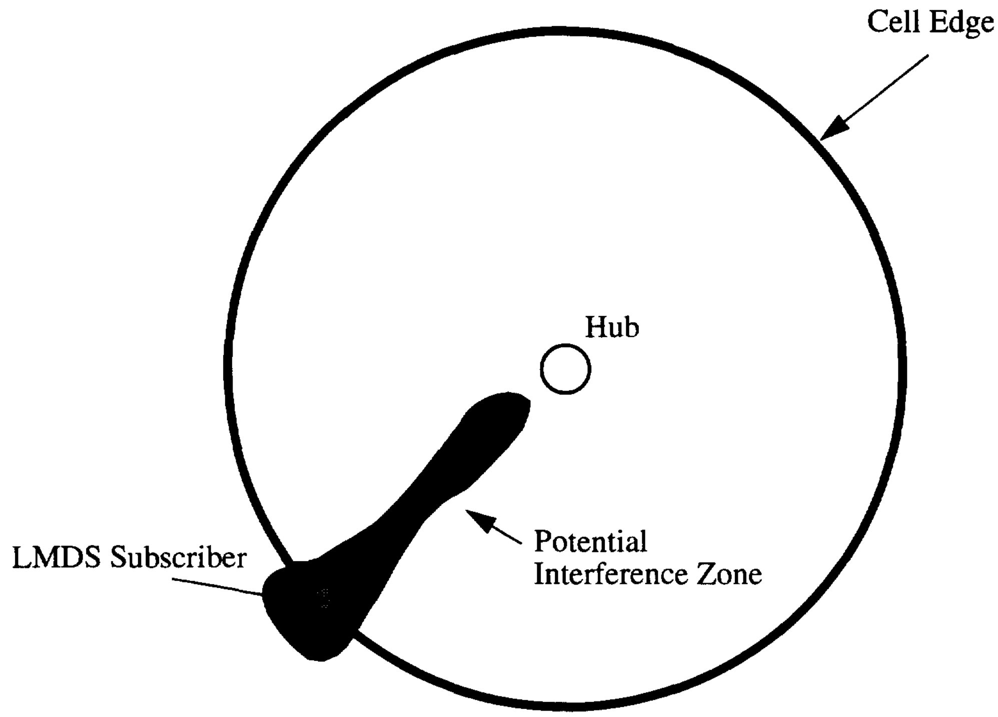

Figure 2-1. Conceptual view of a potential interference zone around an LMDS subscriber receiver.

3. LMDS System Availability

3.1 Introduction

The required separation distance between terminals is useful for determining the potential for interference between a single FSS uplink and a single LMDS subscriber. Aggregation of multiple potential interference zones around LMDS subscriber receivers in a single LMDS cell can be determined as a function of the number of randomly located LMDS subscribers to give the percent of cell area available where FSS uplinks will never cause interference (Figures 6.2-17 through 6.2-23 in the Working Group 1 Report in [1]). These calculations are useful to show the locations where interference can occur, but they do not take into account the number of simultaneously active FSS uplinks. The "Percent of Cell Available" calculations only give the percentage of an LMDS cell where interference will NEVER occur. Hence, they do not give true availability for either an FSS or LMDS system.

The critical measure of the impact of the interference is the resultant availability of the LMDS system due to reduced signal quality caused by interference when both systems are simultaneously operational in the same geographic area. Although each FSS uplink can interfere with multiple LMDS receivers, the number of simultaneous transmissions from FSS uplinks in a given geographic area is limited by the capacity of the satellite system. In the Teledesic system, at most 15 T1 rate (or 1440 16 kbps) standard terminals (TSTs) can be simultaneously operational in a square area 53 km on a side [1], [5]. While the actual number of terminals deployed is expected to be much larger (20 million TSTs worldwide), the capacity bounds the number of terminals that can be simultaneously active in a given area at any one time. Within this area, there may be multiple LMDS cells, and the impact of the interference from the 15 TSTs on the entire LMDS system must be considered on a total LMDS service area basis. A statistical analysis is used to determine LMDS availability in the presence of interference from FSS uplinks. Considering a statistical analysis of the actual amount of interference caused to LMDS receivers is the second step towards achieving a co-frequency sharing solution.

3.2 Road Map

In order to determine the LMDS system availability, several statistical factors such as the number and location of simultaneously active FSS uplink transmissions and weather conditions must be considered. Availability is calculated here as a function of FSS uplink sidelobe level and LMDS minimum required C/(N+I) for interference from T1 rate TST uplinks into the CellularVision and Texas Instruments LMDS systems. Interference from 16 kbps TST and T1 rate SPACEWAY uplinks are discussed later. The following steps are followed to determine LMDS system availability. LMDS availability is the fraction of space and time where LMDS is totally unencumbered. Each step is described in more detail in the following section.

1. Compute the single cell Degradation Distribution as a function of the number of simultaneously active FSS uplinks in a single LMDS cell and weather conditions similar to the Teledesic analysis in [4]. The Degradation Distribution gives the statistical distribution of the percent of LMDS cell area that suffers from harmful

interference based upon a Monte Carlo simulation of all possible FSS uplink locations within a single LMDS cell.

2. Appropriately combine the Degradation Distributions for clear sky and heavy rain conditions.
3. Consider a fixed area of 53 km x 53 km containing one Teledesic "cell" and 64 (8 x 8) LMDS cells. The quotes around "cell" are added here solely to aid the reader by adding emphasis that this is a satellite "cell" and not an LMDS cell.
4. Determine the statistical distribution for the number of simultaneously active T1 rate TSTs in a single LMDS cell based upon the maximum satellite capacity within a single satellite "cell", the number of LMDS cells inside the satellite "cell", and the potential for clustering of FSS transmissions near business centers.
5. Combine the Degradation Distributions for each possible number of simultaneously active FSS uplinks in a single LMDS cell according to the probability of having exactly that number of simultaneously active uplinks in a single LMDS cell. This gives the overall Degradation Distribution; that is, the distribution of the percent of LMDS cell area that suffers from harmful interference as a function of time for a typical cell in the full LMDS deployment within the satellite "cell".
6. Integrate the combined Degradation Distribution to determine the overall system-wide LMDS availability. This availability is the percentage of time that a randomly located LMDS subscriber will experience no harmful interference in any portion of the frequency band, and is calculated as if all subscribers require access to all portions of the band.

3.3 Availability Computation

3.3.1 Degradation Distribution

To investigate the total impact of FSS uplink transmissions on LMDS availability, Monte Carlo simulations were performed for all possible combinations of LMDS system, weather conditions, and number of simultaneous uplink transmissions in a single LMDS cell. Considered individually, the results of these simulations give the Degradation Distribution, the distribution of the percentage of LMDS cell area that experiences reduced signal quality from FSS interference as a function of the input parameters. The concept of Degradation Distribution was presented in [4]. The amount of degradation within an LMDS cell is essentially a function of time due to the changing locations of the active FSS uplinks as FSS subscribers throughout the satellite "cell" initiate and terminate access to the FSS network. The Degradation Distribution gives the probability that a certain percentage or more of the LMDS cell area will experience degraded signal quality a certain percentage of the time. Degradation Distributions are shown in Figure 3-1 for the CellularVision broadcast FM LMDS system with a C/(N+I) threshold of 13 dB with the NRMC transmitter power and subscriber antenna mask, and 1, 2, and 5 simultaneous T1 rate TST transmissions under clear sky and 15 mm/hr heavy rain conditions. Each TST has antenna sidelobes that satisfy the criteria of the ITU mask. In Figure 3-1 with one T1 rate TST in the LMDS cell, 10% of the time, 2% or more of the LMDS cell experiences degraded signal quality. Similarly, 10%

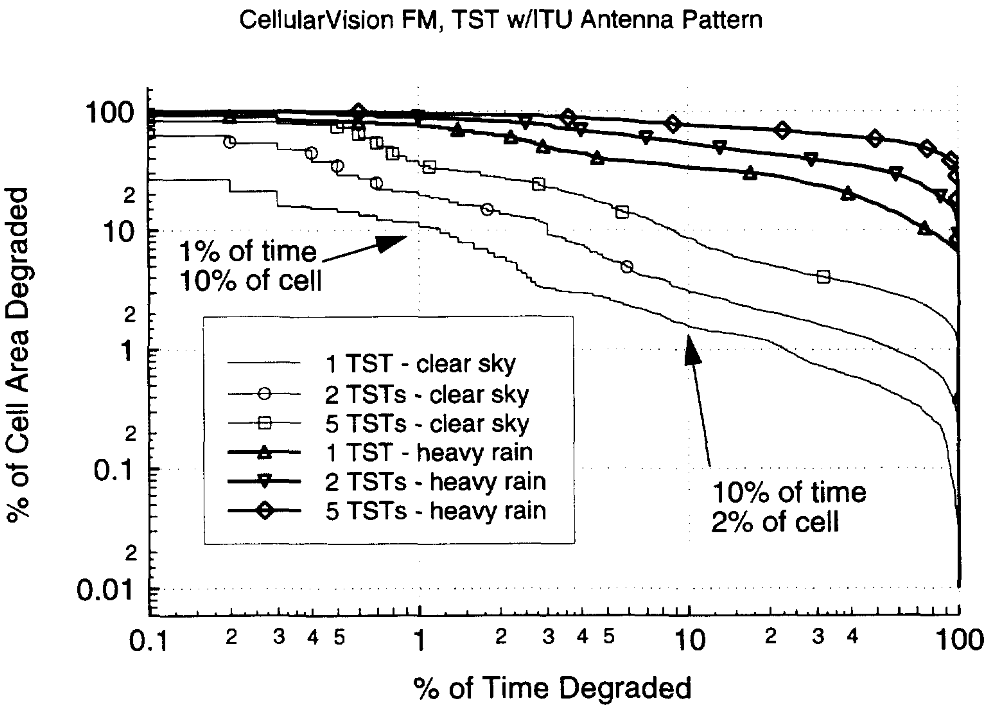

Figure 3-1. Degradation Distribution of the CellularVision hub-to-subscriber link for 1, 2, and 5, simultaneously active T1 rate TST transmissions under clear sky and 15 mm/hr heavy rain conditions.

or more of the cell is degraded only 1% of the time. The Degradation Distribution is an *intermediate* result that shows the amount of cell degradation under a specific set of conditions. The probability of occurrence of each possible set of special conditions must be considered in determining the overall LMDS system-wide availability.

3.3.2 Including the Effects of Heavy Rain

The effects of increased interference due to the use of FSS uplink power control to increase the transmitter power under conditions of heavy rain are included by using the clear sky Degradation Distribution results for 99% of the time and the heavy rain results for 1% of the time. The heavy rain results were computed for the 99.9% rain rate in climatological region D_2 (New York, 15 mm/hr), providing a conservative estimate of the effects of rain. Effectively, the heavy rain condition is included in the calculations ten times more often than will occur in practice. Ideally, the Degradation Distribution should be computed as a function of rain rate and averaged over the rain rate distribution, an extremely computer-intensive task. The "two-step" rain rate distribution used here conservatively upper-bounds the effect of rain on the overall Degradation Distribution.

3.3.3 Location of Active FSS Uplinks

The location of active FSS uplinks within an LMDS cell is included in the computation of the Degradation Distribution via Monte Carlo simulation. Each uplink is assumed to be randomly located within the borders of the LMDS cell. Teledesic has correctly shown in [4] that an uplink located near the center of an LMDS cell can potentially cause interference throughout a greater percent of the cell area than can an uplink located near the cell edge. The present analysis includes the effects of FSS uplinks located both near the hub and near the cell edge according to the statistical likelihood of an uplink being near the hub as determined by the cell geometry.

For the CellularVision and Texas Instruments systems considered here, sixty-four (8 by 8) 5 km radius LMDS cells are placed in a single 53 km by 53 km Teledesic Earth-fixed "cell". A small amount of overlap does not significantly impact the calculations, and is ignored. The resultant LMDS cell shape is square with the radius distance being from the hub to the "corner" of the cell as shown in Figure 3-2. LMDS hubs are located at the center of each cell, and each subscriber's antenna is pointed toward the nearest hub. FSS uplinks may be located anywhere within the Teledesic "cell", and the statistical distribution of the number of simultaneously active uplinks in an LMDS cell must be determined.

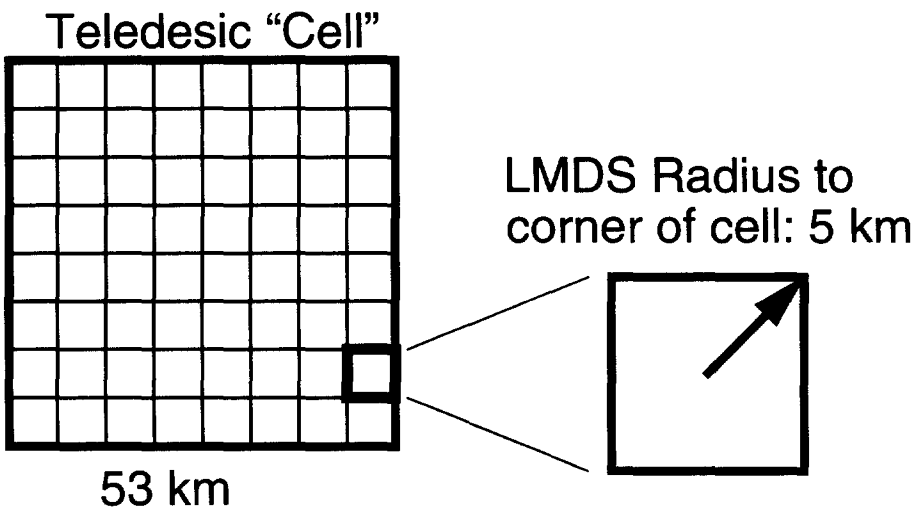

Figure 3-2. Geographic area used to compute LMDS system availability in the presence of interference from Teledesic Standard Terminal uplinks.

It is appropriate to use the binomial distribution to model the number of simultaneously active FSS uplinks in each LMDS cell. Consider a *single* LMDS cell and a fully loaded satellite capacity of 15 T1 rate TSTs. For a uniform distribution of FSS uplinks, each FSS uplink has a probability of 1/64 of being in this particular LMDS cell. The binomial distribution describes the outcome of repeated independent trials with constant probability p of success. The probability of exactly x successes in N trials can be written as [6]

$$f(x) = C(N,x)p^x(1-p)^{N-x} \tag{3-1}$$

where

$$C(N,x) = \frac{N!}{x!\,(N-x)!} \tag{3-2}$$

Hence, the binomial distribution with p=1/64 and N=15 can be used to describe the probability that x number of uniformly distributed FSS uplinks are in a given LMDS cell.

Clustering of the FSS uplinks in a small portion of the Teledesic "cell" is easily accommodated. IF all active FSS uplinks were clustered in Y LMDS cells, the probability of being in a particular LMDS cell is $1/Y$ for those Y cells, and zero for the 64-Y other cells. This is modeled by the binomial distribution with $p=1/Y$ and N=15. Table 3-1 shows the probability of having zero through fifteen simultaneous uplink transmissions in a single LMDS cell for a uniform distribution of FSS uplinks and for FSS uplinks clustered uniformly in 8, 4, or 2 LMDS cells. For a uniform geographic distribution of uplink traffic, an LMDS cell will have no active uplinks within its borders 79% of the time. When the uplink traffic is clustered over a smaller number (e.g., 8, 4, or 2) of LMDS cells, the probability of having a greater number of simultaneously active transmissions increases in those cells. In the remaining cells (e.g., 56, 60, or 62), there are NO FSS uplinks to cause LMDS performance degradation. Notice that even when all of the uplink traffic is clustered in just two LMDS cells (3% of the Teledesic single "cell" service area), the probability of all fifteen simultaneously active transmissions occurring in a single LMDS cell is only 3×10^{-5}. Clustering equivalent to 90% of the users in 10% of the area gives a probability p of approximately 1/7.11. Hence, the clustering considered here is more severe than if 90% of the active users were located in 10% of the area.

Table 3-1. Binomial coefficients for the probability of zero to fifteen simultaneous T1 rate TST transmissions for different assumptions on clustering of uplink traffic across the 53 km by 53 km Teledesic "cell".

Number of Simultaneous Transmissions in Cell	p=1/64	p=1/8	p=1/4	p=1/2
Cluster Size ->	**64 Cells**	**8 Cells**	**4 Cells**	**2 Cells**
0	0.7896	0.1349	0.0134	$3x10^{-5}$
1	0.1880	0.2892	0.0668	0.0004
2	0.0209	0.2892	0.1559	0.0032
3	0.0014	0.1790	0.2252	0.0139
4	0.0001	0.0767	0.2252	0.0417
5	~	0.0241	0.1652	0.0916
6	~	0.0057	0.0917	0.1527
7	~	0.0011	0.0393	0.1964
8	~	0.0001	0.0131	0.1964
9	~	~	0.0034	0.1527
10	~	~	0.0007	0.0916
11	~	~	0.0001	0.0417
12	~	~	~	0.0139
13	~	~	~	0.0032
14	~	~	~	0.0004
15	~	~	~	$3x10^{-5}$

The binomial distribution is used to weight and combine the Degradation Distributions computed for zero to fifteen simultaneously active T1 rate interferers according to the appropriate probability of occurrence of each number (0-15) of simultaneously active uplinks in a cell. For clustered FSS uplink traffic, the combined Degradation Distribution represents the LMDS performance in the cells where the uplinks are clustered. The system-wide Degradation Distribution for CellularVision hub-to-subscriber links with the NRMC link budget computed in this manner is shown in Figure 3-3 for 15 uniformly distributed simultaneously active T1 rate TSTs. The different curves in Figure 3-3 represent different values of FSS uplink antenna sidelobe discrimination relative to the boresight gain. For example, for a 38 dB sidelobe discrimination (ITU antenna mask), there is only a 6% probability that 1% or more of an LMDS cell will have performance degraded below a C/(N+I) of 13 dB.

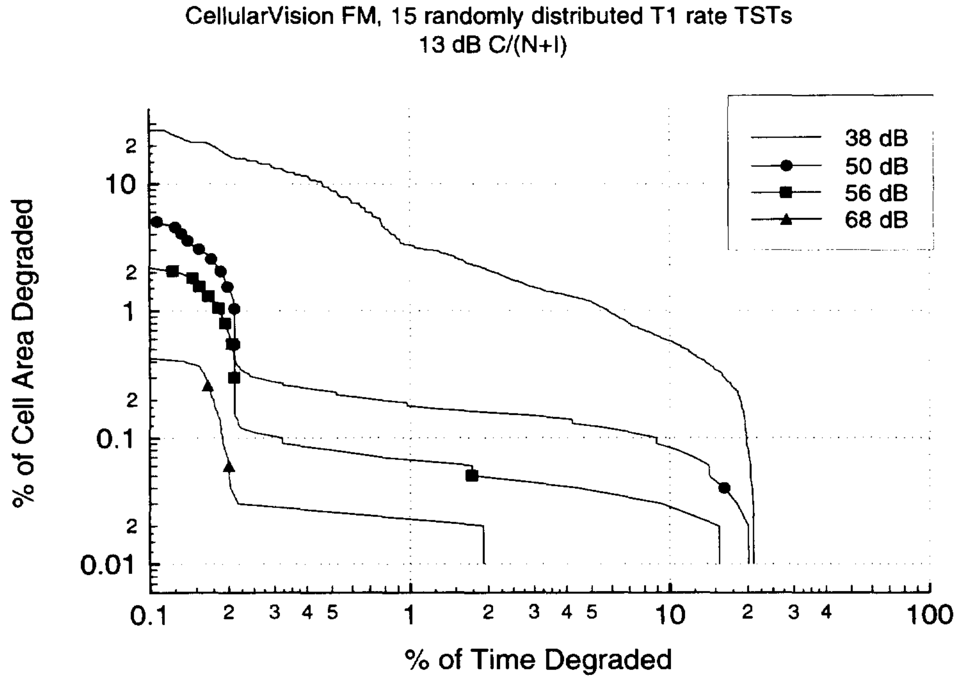

Figure 3-3. System-wide Degradation Distribution for CellularVision hub-to-subscriber links with a uniform geographic distribution of T1 rate TST uplinks as a function of FSS uplink antenna sidelobe discrimination.

3.3.4 Availability

The Degradation Distribution gives the joint space-time distribution of the percent of LMDS cell area that is degraded. Integration of the Degradation Distribution over time reduces the two dimensions to one, giving the overall availability. This availability is the availability of the entire shared portion of the frequency band as a function of FSS uplink antenna sidelobe level for the assumed distribution of geographic clustering of FSS uplink transmissions. The system-wide availability is computed as the weighted average of the availability in the cells where FSS uplinks are clustered and the availability (100% available) in the other cells.

3.4 Results of Availability Calculations for T1 Rate TST Interferers

The previous section details the method for calculating LMDS availability in the presence of T1 rate TST uplinks. This section presents the calculated availability under a range of possible FSS uplink geographic clustering and sidelobe levels, and LMDS C/(N+I). The computed CellularVision hub-to-subscriber link availability with the modified link budget in Table 1-1 in the presence of 15 T1 rate TSTs with the ITU antenna pattern mask is shown in Figure 3-4. The percent availability (100-degradation) is presented as a function of the required C/(N+I) for the LMDS system for a uniform distribution of FSS uplinks and for geographic clustering of FSS uplinks in 2, 4, and 8 LMDS cells. The required C/(N+I) can be viewed as the resultant LMDS signal quality. For the CellularVision 18 MHz FM video signal, a C/(N+I) threshold of roughly 8 dB is considered to represent where the picture quality becomes intolerable. A threshold of 13 dB represents a picture quality of at least 'Fine' (42 dB SNR, comparable to cable), and a threshold of 18 dB gives a video picture quality that is 'Fine to Excellent'. Hence, for the worst channel of a typical LMDS subscriber, an 'Excellent' quality picture will be received 99.57% of the time, a degraded picture quality ('Fine to Excellent') will occur 0.28% of the time, a degraded picture quality ('Fine') will occur 0.09% of the time, and the picture quality will be below 'Passable to Fine' 0.06% of the time due to interference from 15 simultaneously active randomly located T1 rate TST uplinks. For a C/(N+I) of roughly 11 dB, the availability is 99.9%.

The upper three curves in Figure 3-4 indicate the unavailability in the LMDS cells where the FSS uplinks are clustered. As expected, the performance in those few cells degrades as the uplinks are clustered more closely together. However, the lower curves (bunched together) show the unavailability across the entire geographic area under study. It can be seen from Figure 3-4 that the *system-wide performance* when FSS uplinks are clustered in a small number of LMDS cells is no worse than when FSS uplinks are uniformly distributed at random locations throughout a 53 km by 53 km square area. This occurs because each active FSS uplink generates a small degradation zone. To first order, the overall availability

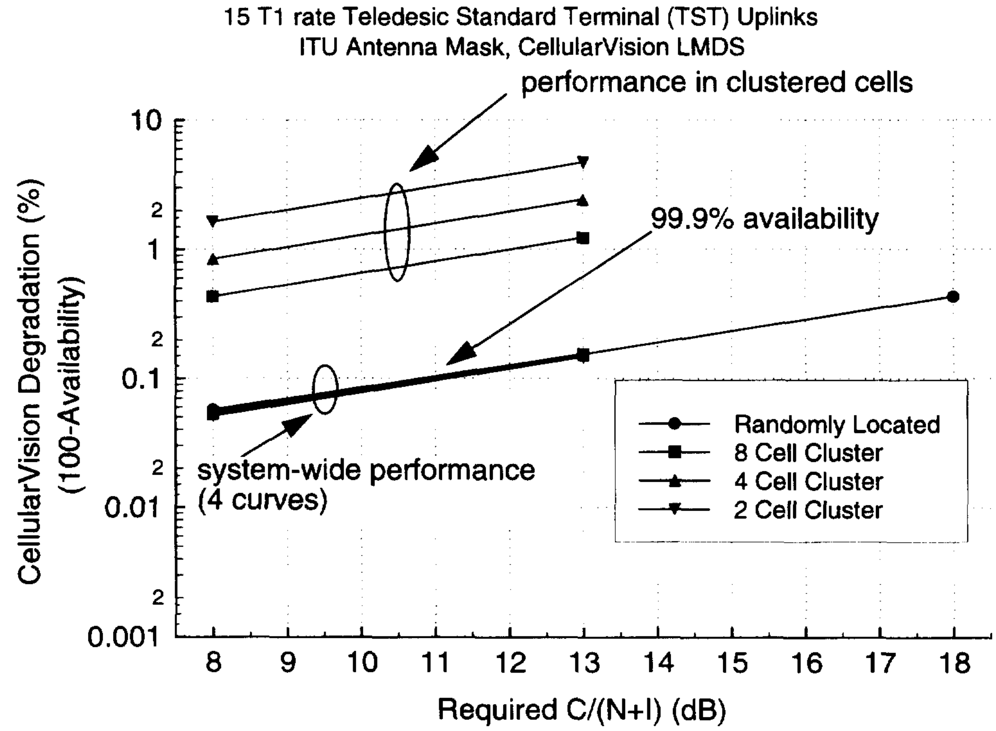

Figure 3-4. Degradation (100-Availability) of CellularVision hub-to-subscriber link as a function of required C/(N+I) and geographic clustering. Both the degradation in the clustered cells and the system-wide degradation are given for 15 simultaneously active T1 rate TST uplinks with the ITU antenna pattern mask in the clustered cells.

is not affected by clustering these zones in a few cells or distributing them uniformly over the entire area. Although the availability in the cells where active FSS uplinks are clustered is decreased, the availability in the other cells is 100% leading to a system-wide performance that is comparable to uniformly distributed uplinks. The calculations assume that 15 simultaneously active uplinks are *always* clustered in those few cells. Under actual traffic conditions, there will often be less than the maximum of 15 simultaneously active uplink terminals. Also, uplinks in LMDS cells other than where clustering is highest will access the FSS network reducing the average traffic in the clustered cells. The actual LMDS availability will be greater than the calculated availability, even in the cells where FSS uplink traffic is densely clustered. For a C/(N+I) threshold of 11 dB, the calculated system-wide LMDS availability for the parameters given in the NRMC is 99.9%. At a C/(N+I) of 8 dB, which represents a picture quality of 'Passable to Fine', the availability is 99.94%

Section 2.3 showed that the required minimum separation distances for the CellularVision and the Texas Instruments LMDS systems were approximately the same with the LMDS system modifications proposed here (see Table 2-2 and Table 2-3). Hence, it is expected that the availability performance of the two systems in the presence of interference from FSS uplinks will be comparable. Performance of the 52 Mbps QPSK LMDS system described by Texas Instruments to the NRMC in the presence of interference from 15 simultaneously active T1 rate TST interferers is shown in Figure 3-5 to confirm this

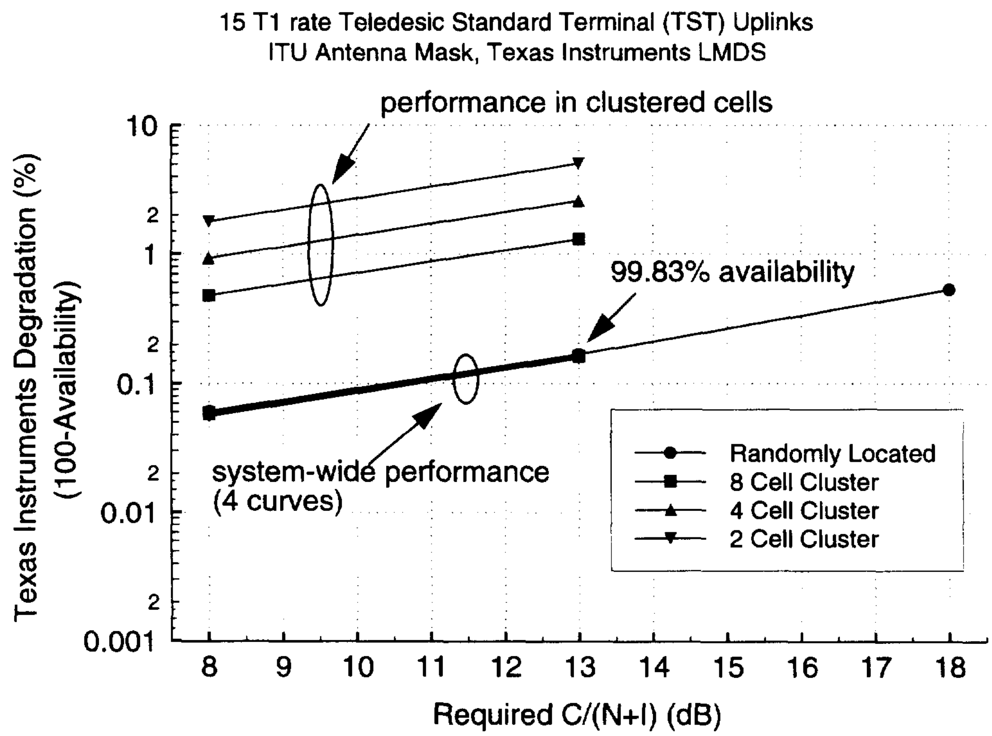

Figure 3-5. Degradation (100-Availability) of Texas Instruments hub-to-subscriber link as a function of required C/(N+I) and geographic clustering. Both the degradation in the clustered cells and the system-wide degradation are given for 15 simultaneously active T1 rate TST uplinks with the ITU antenna pattern mask in the clustered cells.